Experimental Studies in a Reconfigurable C4 Test-bed for Network Enabled Capability

Prof N. A. Stanton, Dr G. H. Walker, Mr P. M. Salmon, Dr S. Gulliver, D. Jenkins, Miss Darshna Ladva, Miss Laura Rafferty, Dr M. S. Young, Prof S. Watts, Dr C. Baber[1], Dr J. Cross[1], Dr R. Houghton[1], and Mr R. McMaster[1]
Defence Technology Centre for Human factors Integration (DTC HFI)
BITlab, School of Engineering and Design, Brunel University,
Uxbridge, Middlesex, UB8 3PH, UK
[1]School of Electronic and Electrical Engineering, University of Birmingham,
Edgbaston, Birmingham, B15 2TT, UK

ABSTRACT

This paper reports on the development of a command and control environment that enables experimental studies to be conducted into Network Enabled Capability (NEC). The command and control environment comprises a reconfigurable Command Wall, and wireless local area network and reconfigurable wearable computers. The two studies reported in this paper explore communication media (study one) and data source/decay (study two). Study one showed the advantages and disadvantages of the electronic medium for passing data between the field and command room. Study two explored data push versus data pull and the effects of data decay on some aspects of command performance. As an experimental environment the reconfigurable C4 test-bed is now beginning to show some utility. Further studies are being planned and scenarios are being developed.

KEYWORDS: Command and Control, Communication Media, Data Push and Pull

*Corresponding author:
email: neville.stanton@brunel.ac.uk
phone: +44 (0) 1895 265543

NETWORK ENABLED CAPABILITY

Networked Enabled Capability (NEC) offers a vision of interoperable technological systems that will help realise plans for an integrated and integrating digital battle-space. NEC has the potential to *collect, fuse, and disseminate accurate, timely and relevant information to all levels allowing a more informed assessment of enemy and friendly forces, intentions and capabilities, and the potential to generate synchronised effects across the battle-space*. The basic tenet sustaining this view is that military operations would be able to conduct joined-up operations rather with a jointly compiled electronic operational picture on which coordinated missions and responses could be orchestrated. Realising this vision requires significant technical challenges to be overcome. Even if this is realised the systems will not achieve maximum potential unless a deeper understanding of the human dimensions of electronically networked systems are advanced. One means of advancing knowledge is to gather data from experimental environments in which the key variables are systematically manipulated.

In a review of team work research, Annett & Stanton (2000) argue that the contemporary issues include the structure of the team, training of the team, and development of the human-machine interface. These

Stanton, N.A.; Walker, G.H.; Salmon, P.M.; Gulliver, S.; Jenkins, D.; Ladva, D.; Rafferty, L.; Young, M.S.; Watts, S.; Baber, C.; Cross, J.; Houghton, R.; McMaster, R. (2006) Experimental Studies in a Reconfigurable C4 Test-bed for Network Enabled Capability. In *Virtual Media for Military Applications* (pp. 4-1 – 4-8). Meeting Proceedings RTO-MP-HFM-136, Paper 4. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

Report Documentation Page						*Form Approved* *OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.						
1. REPORT DATE **01 JUN 2006**		2. REPORT TYPE **N/A**				3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Experimental Studies in a Reconfigurable C4 Test-bed for Network Enabled Capability**						5a. CONTRACT NUMBER
						5b. GRANT NUMBER
						5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)						5d. PROJECT NUMBER
						5e. TASK NUMBER
						5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Defence Technology Centre for Human factors Integration (DTC HFI) BITlab, School of Engineering and Design, Brunel University, Uxbridge, Middlesex, UB8 3PH, UK**						8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)						10. SPONSOR/MONITOR’S ACRONYM(S)
						11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**						
13. SUPPLEMENTARY NOTES **See also ADM002024., The original document contains color images.**						
14. ABSTRACT						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**8**		

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

issues are particularly pertinent to NEC research. Carletta et al (2000) present an optimistic picture for distributed team work. They suggest that a relatively modest level of technology can support collaborative working, despite the distribution of the team members. They do point out however, that distributed team working may affect the dynamics of the team and practical issues, such as turn-taking in discussions, need to be resolved. This may require new ways of thinking about the design of interface technologies, to support collaborative decision making by team members.

An experimental study of technologically mediated command and control activities focused on the effects of location of team members, communication medium and type of C4 task on the performance of the team (Stanton et al, 2002). The study showed that all of these variables interact, such that some tasks are better performed remotely whilst others are performed better face-to-face, and that some tasks are better suited to one communication medium over another. It is these subtle interactions that are difficult to predict in designing NEC environments. Therefore optimal performance of NEC environments is bound to place a strong reliance on Human Factors research for socio-technical systems design.

Team work in military domains places particularly high demands on people, such as factors associated with hostile environments, high temporal demand, and threat of injury (McCann 2000; Annett et al 2000; Artman 2000; Paris et al 2000). The way in which the team make, or fail to make, effective decisions are one of the central topics to be considered. Jones & Roelofsama (2000) suggest that pathological biases in decision making may result from incorrect shared situation awareness, by bolstering mislaid confidence. Smith & Dowell (2000) also show that poor shared situation awareness can lead to conflict in inter-agency co-ordination. Other researchers have suggested ways for improving shared situation awareness, such as by improving feedback (Rasker et al 2000), team design (Stanton & Ashleigh 2000), and presenting information serially without time stress (Artman 2000).

In a recent Ministry of Defence document on NEC (MoD, 2005, JSP 777 edition 1), it was stated that: “The primary challenge of NEC is to fully incorporate the human dimension into the development of NEC.” (page 9). It was also pointed out that in order to fully realise the potential of NEC will require “purposeful and effective research, analysis and experimentation.” The purpose of this paper is to report on the progress of the Reconfigurable C4 (Command, Control, Communication and Computers) test-bed developed specifically for experimental studies into NEC by the Human Factors Integration Defence Technology Centre (HFI-DTC).

DEVELOPMENT OF THE TESTBED

In brief, the C4 test-bed comprises a Command Wall, which is approximately 9 metres long by 2 metres high, eight wearable computers for ground-based mobile personnel, and software and hardware architectures that enable communications and data to pass between the wearable computers (developed at the University of Birmingham) and the Command Wall (developed at Brunel University).

Development began with a highly accurate 3D model of the campus of Brunel University. The model was created from theodolite data carried out by a survey team over the course of seven months. This data was in the form of a layered AutoCAD model, with each layer representing a different type of architectural form, e.g. building outlines, shrubbery, and river and so on. Textures were created from high-resolution digital photographs. Once the model was constructed, code was then written to enable tracked entities to be placed and positioned on the model. Live tracking of blue forces was taken from the mobile units and transmitted to the Command Wall via a wireless local area network (WLAN). The mobile units were designed specifically for the project and run bespoke software. The computer runs Windows XP and has the power of a modern desktop machine. The box housing the computer is approximately palm sized and can be attached to any part of the body. The user of the wearable computer interacts with it via a thumb scroll mouse and buttons.

A protocol has been developed for passing data between the Command Wall and the Wearable Computers, so that positional information of hostile, friendly, and neutral entities can be reported to the Command Wall. The updated information can be passed back to all mobile units. Mobile units can also be sent to investigate unclassified entities and report on their status. Three large Stewart screens with rear projection for the peripheral screens and a front projector for the centre screen were installed in our laboratory. Six Eiki LC-SX4Li projectors are projected onto three 3m by 2.25m Stewart projections screens, the peripheral screens rotated by 45 degrees from the centre screen (Green et al, 2004, 2005).

The Command Wall is split into three distinct areas: strategy and planning area, 3-D map area for up-to-date information about the position of the mobile units and other entities in the area of interest, and communications area for video, audio and text. The command wall is the primary interface for the commander in the C4 test-bed. The large size means that several observers can view the command wall at the same time. Tasks can be assigned to the planning, 3D map and communications areas as appropriate for any mission scenario.

The design of the Command Wall aims to support the four main phases of C4 missions: planning, rehearsal, action and review. Planning tasks comprise receiving the mission effect order and developing plans with operational orders. Rehearsal tasks comprise a walk-through the plan and identifying when and where planned actions are to be undertaken. The walk-though can be at the eye-level view on the 3D map at the planned pace of the action, or at a plan view at any speed. Action tasks comprise the execution of the plan and employing contingency plans as required. As mentioned before, data can be transmitted and received in real time between the Command Wall and Wearable Computers. After action review tasks comprise comparing the actions to the plans and identifying lessons learnt. A replay facility in the Command Wall can replay all of the data at the required speed. Fast forward and rewind features are available. The data store structure enables random access to any point in the mission.

RESEARCH QUESTIONS

Consistent with the desires to “fully incorporate the human dimension” , the main research questions for the experimental programme are concerned with agility, situation awareness and team working. As pointed out in JSP-777, NEC has the potential to influence the way in which operations are conducted and enable operations to be conducted at a much higher tempo. The agility research question addresses the ability of NEC to adapt to changing circumstances and reconfigure the groupings and networks as required to take advantage of any opportunity that arises. The situation awareness research question addresses the ability of NEC to appropriate information to the relevant personnel in order to enable then to have decision superiority in any context. The team work research question addresses the ability of NEC to foster effective working between and within team structures. Obviously there will be interactions between each of these research questions.

The study scenarios are based on urban operations, such as controlling a section of road to allow supplies to pass through. Brunel and Birmingham campuses are being used as the urban environments for the experimental work. Tasks within the scenario include way-finding, identification and classification of structures, reconnaissance of entities without any classification, tracking of hostile entity movements, developing tactical plans for movement with and without engagement, defending a building and containing a building.

Within these task scenarios, the studies are investigating the effects of different communication media (e.g., data-link, video, voice and text), different communication structures (e.g., hierarchical, peer-to-peer and party line) and different network structures (e.g., star, circle, chain, etc,). In addition, different interfaces and i/o peripherals for the mobile units and Command Wall are also being examined.

STUDY 1: Communication media

There is a growing body of evidence to suggest that the nature of the communication media through which team interaction takes place will have a significant effect on team performance. A number of studies have been carried out which have compared teams performing idea generation tasks face to face using verbal communication with teams performing the same task using computer mediated communication, see McGrath & Hollingshead (1994) or Guzzo & Salas (1995) for reviews. Communication media will vary in the extent to which they can support different communication channels. Daft and Lengel (1986) conceptualised this in terms of "media richness". They suggested that media differ in their capacity to transmit the meaning of information on four information richness dimensions: feedback; multiple cues; language variety; and personal focus, such that a medium's potential richness is the sum of scores on each of these dimensions. Media which are high on these dimension, i.e. immediate feedback, multiple cues etc., are considered rich, whilst those that are low on these dimensions are considered poor. Virtually any restriction of communication modality or channel effects the breadth and redundancy of cues available for smoothing the flow of communication. It may be necessary to deliberately create effective devices for facilitating communication in such groups, for example to aid turn-taking. It also appears to affect the interpersonal content in group communication relating to negotiation, conflict resolution and status attainment. This in turn leads to varying results depending on how important these elements are to successfully completing the task (McGrath, 1990). Media, when viewed in terms of media richness, vary in the extent to which they can influence the reduction of uncertainty and equivocality. If a medium is too rich for a particular task, efficiency losses may occur due to distraction. If a medium is too poor effectiveness losses might occur due to too little information being available, making it hard for team members to understand others interpretations of the task. Lying between these poles is a domain of effective information processing, in which the richness of the media adequately meets the requirements of the task. McGrath & Hollingshead (1994) propose that there is a best fit for task media interactions.

Study one was conducted to examine the effects of three mdeia; command wall technique (electronic), embodied by the Brunel command wall system, compared to a traditional paper map technique (paper) and a traditional radio and map technique (radio). The participants, acting in the role of commander, were randomly assigned to one of these techniques (a between subjects design). Their task was to undertake a Battlefield Area Evaluation (BAE), in which the main output was a Situation Overlay representing the actual state of the Battlespace. Information used in the construction of the Situation Overlay was extracted from the environment by three Field Agents who reported on specific informational artefacts placed around a defined search area.

The aims of the study were:

- To discover whether or not there are significant differences between the three systems, and if so what these are.
- To discover any improvements that could be made, from a user perspective, to the new electronic C4i system.

There were some clear human performance implications arising from the use of each command technology. The electronic (command wall) condition was associated with significantly quicker performance, with respect to creating the situation overlay, compared to both of the other conditions. The radio condition, however, did have a significantly faster decision time than the electronic condition. There were no significant differences for decision 'accuracy' (the percentage of correct features) between the three conditions, although the electronic system led to significantly less features being missed from the situation overlay than the paper system. In terms of situational awareness, there is evidence to suggest that the type and structure of knowledge differs between the three conditions. No significant differences were detected for mental workload, usability and, importantly, decision quality. Although there were no improvements on these dimensions between the conditions, there were also no decrements. Therefore, despite differences in situational awareness, the electronic condition enables commander's to achieve comparable levels of decision quality, workload, and usability, but quicker than traditional techniques.

The exercise also revealed a number of further issues to be carried forward into the design of the electronic system, for example, the decision exercise and the temporal aspects of the scenario are both features that warrant further attention.

STUDY 2: Information push-pull

The current study reports on the human performance outcomes when these two variables are experimentally manipulated. The motivation for examining information Push/Pull is derived from an earlier study where it was cited as a possible explanatory factor in the results gained when comparing different command technologies; specifically, that decision time seemed to be affected by information source type (Push or Pull).

The literature on information source type contains a number of different viewpoints and contrasting findings. The view of Weber and Aha (2002), and indeed, most other authors on this topic, is that "Push" methods are preferable. They explain that "Pull" methods involve users "completely [devoting] his or her attention to the source and therefore will only capture desired information. They have the entire burden and must search for the information themselves". Information Pull "requires that the users know a priori where and when to look for data or that they spend an inordinate amount of time polling known locations for updates or new information" (Cybenko & Brewington 1998). "Push" methods are defined as an attempt to "'relieve the burden on the users', as they do not have to take the initiative to search for information, instead it is sent to them when it is considered it is needed". Information Push transfers control from the users to the data providers. It means that users may not have to invest as much time sourcing information, however, what information they receive may not always be relevant (Cybenko & Brewington 1998); so there are some disadvantages. Lynch and Gregor (2003) and Cheverst, Mitchell and Davie (2006) are equivocal in their views. The general verdict seems to be a mixture of positive and negative affects, which include the amount of task interruption, the amount of user control, the amount of effort needed to retrieve information, and so forth. The separate findings are in themselves perhaps not as interesting as the context in which those findings emerge. In other words, previous literature seems to have had the same issues as the previous study in isolating information source from the task context, that is, it can be said to be highly context dependent.

In study one (which was the motivation for the study two) an unusual and difficult to explain finding emerged that appeared to be related to information source type. In the previous study three command technologies were compared: an electronic system comprised of the Brunel Command System/Knowledge Wall, a radio based system using paper maps and overlays, and a paper system based on a list of coordinates (plus maps and overlays). Although the electronic condition appeared to confer some time advantages (for no apparent trade off in usability, mental workload and decision quality), decision making time took significantly longer than the radio condition. It was hypothesised that this counter intuitive finding emerged due to 'depth of processing', the nature of the task, information source, or a combination of both.

The electronic condition embodied information Push. Field Agents updated, live, an electronic map of the battlespace; the information was not directly solicited by the commander. In the paper and radio conditions the commander "requested and received specific information"; it was Pulled. There is an added factor, that of information permanence. In the electronic condition the Field Agent inserted a piece of (not directly solicited) information into the map and that item remained on the map (to be referred to at will) for the duration of the study. The same was true of the paper condition where there was a list of artefacts that they could refer to throughout. The radio condition was different. Due to the verbal nature of the communications, the commander could not refer to previous information after it had been delivered (except to request that the last transmission be repeated). The information, therefore, was Temporary. Information permanence is a facet that Cheverst, Mitchell and Davie (2006) identified in their work, in particular, the issue of 'not forgetting' and the 'over riding of old information when new information becomes available'.

The motivation for the study two was provided by the previous examination of command technology. The main aim of the current study was to isolate the effects of information source type (whether information is Pushed to the commander, or Pulled by them) and information permanence (whether information remains available for the duration of the study or whether it is only available for a short time).

The participants, who acted in the role of commander, were randomly assigned to one of four information source/decay conditions (Push Permanent, Push Temporary, Pull Permanent and Pull Temporary), therefore, this was a between subjects design. The specific task of the commander was to undertake a Battlefield Area Evaluation (BAE). The main output of the task was the commander's (graphical) interpretation of the actual state of the Battle-space (a form of Situation Overlay). Information used in the construction of the Situation Overlay was extracted from the environment by three Field Agents.

The specific aims of the study were to ascertain whether there was any statistical association between information source type and decay on the outcome measures of: task completion time, situation overlay accuracy, situational awareness, mental workload, decision quality and depth of processing. The results of the analysis suggest that any effect of information source type and decay is largely confined to time, accuracy and SA (as were the main effects of the previous study). The permanence of information was revealed to be a more powerful factor than source type.

CONCLUSIONS

In conclusion, this paper has sought to present the development of a reconfigurable C4 test-bed which has been developed specifically for conducting experimental investigations into the human dimensions of NEC environments. Study one showed some advantages for the electronic medium. Kiesler, Siegal & McGuire (1984) suggest that computer-mediation reduces status effects, thereby encouraging team members to participate more fully and relieving the co-ordiator of some of the workload. The voice medium may also put extra demands on the co-ordinator by its very nature. There are distinct differences in the manner and nature of communication between voice and computer messages. In essence, the computer places fewer requirements on memory, is less ambiguous and requires more planning. This leads to a generally more successful outcome. However, there are some drawbacks. The computer mediated exchanges of data are generally more impersonal, which might have implications for trust.

The efficacy of information Push/Pull depends on the operational context. It seems perfectly reasonable to suppose that in certain command architectures the possible disadvantages of both could be overcome with the provision of certain controls. For example, the concept of 'information sharing' (Dekker, 2002) may well provide the degree of shared (or distributed) situational awareness that enables only "relevant" information to be "Pushed". Similarly, knowledge base development and management processes could minimise the time that needs to be invested in searching out relevant information, and a role such as 'knowledge base manager' could further increase the efficiency of information that is "Pulled". It would appear that complex command and control systems involve a combination of both information Push and Pull, therefore, in any experimental study that seeks to isolate this factor, the command architecture must be held constant between conditions.

The studies reported in this paper show that the test-bed is now functional. Research scenarios are being developed, so that the experiments can have military relevance. Experimental studies are necessary because much of the underpinning understanding of how performance of these systems may be optimised just does not yet exist.

ACKNOWLEDGEMENTS

This work from the Human Factors Integration Defence Technology Centre was part-funded by the Human Sciences Domain of the UK Ministry of Defence Scientific Research Programme.

REFERENCES

Annett, J., Cunningham, D. and Mathias-Jones, P. (2000) A method for measuring team skills, *Ergonomics* 43 (8) 1045-1051.

Annett, J. and Stanton, N. A. (2000) Team work: A problem for Ergonomics?. *Ergonomics* 43 (8) 1076-1094.

Artman, H. (2000) Team situation assessment and information distribution. *Ergonomics* 43 (8) 1111-1128.

Carletta, J., Anderson, A. H. and McEwan, R. (2000) Team situation assessment and information distribution. *Ergonomics* 43 (8) 1237-1251.

Cheverst, K., Mitchell, K., & Davies, N. (2006). *Investigating Context-aware Information Push Vs Information Pull to Tourists.* Available on-line at: www.cis.strath.ac.uk/~mdd/mobilehci01/procs/cheverst_cr.pdf.

Cybenko. G & Brewington. B. (1998) The Foundations of Information Push and Pull. Mathematics of information. Springer-Verlag.

Daft, R.L., & Lengel, R.H., (1986). Organisational Information requirements, media richness and structural design. *Management Science*, *36 (6)*, 698-703.

Dekker, A. H. (2002) *C4ISR architectures, social network analysis and the FINC methodology: An experiment in military organisational structure.* DSTO Electronics and Surveillance Research Laboratory. Edinburgh, South Australia.

Green, D., Stanton, N. A., Walker, G. H. & Salmon, P. (2004) Using Wireless Technology to develop a virtual reality command and control centre. *ICETE 2004 International Conference on E-Business and TElecommunicatons Networks*, Setúbal/Portugal.

Green, D., Stanton, N., Walker, G. H., & Salmon. P. (2005) Using wireless technology to develop a virtual reality command and control centre. *Special Issue of Virtual Reality – Virtual Environments for Defence Applications*, 8 (3) 147-155.

Guzzo, R.A. & Salas, E. (1995). *Team Effectiveness and Decision Making in Organisations.* Jossey-Bass; San Francisco.

Jones, P. E. and Roelofsama, P. H. M. P. (2000) The potential for social contextual and group biases in team decision making: biases, conditions and psychological mechanisms *Ergonomics* 43 (8) 1129-1152.

Kiesler, S.; Siegal, J. & Mcguire, T. W. (1984) Social psychological aspects of comuter-mediated communication. *American Psychologist*, 39, 1123-1134.

McCann, C., Baranski, J. V., Thompson, M. M. and Pigeau, R. A. (2000) On the utility of experiential cross-training for team decision making under time stress.. *Ergonomics* 43 (8) 1095-1110.

McGrath, J.E & Hollingshead, A.B. (1994). *Groups interacting with technology*. Sage Publications: London.

MoD (2005) *Network Enabled Capability*. JSP 777 edition 1. MoD, UK.

Paris, C. R.; Salas, E. And Cannon-Bowers, J. A. (2000) Teamwork in multi-person systems: a review and analysis. *Ergonomics*, 43 (8), 1952-1075.

Rasker, P. C., Post, J. M. and Schraagen, J. M. C. (2000) Effects of two types of intra-team feedback on developing a shared mental model in command and control teams. *Ergonomics* 43 (8) 1176-1189.

Smith, W. and Dowell, J. (2000) A case study of coordinative decision making in disaster management. *Ergonomics* 43 (8) 1153-1166.

Stanton, N. A. and Ashleigh, M. (2000) A field study of team working in a new human supervisory control system. *Ergonomics* 43 (8) 1190-1209.

Stanton, N. A., Connelly, V., Prichard, J., and van Vugt, M. (2002) Assessing the effects of location, media and task type on team performance. *Journal of Defence Studies*, 7 (1) 29-41.

Lynch, T. & Gregor, S. (2003) *Socio-technical and human cognition elements of information systems* (pp 158-180) Hershey, USA. Idea Group Publishing.

Weber, R.O. & Aha, D. W. (2002) *Intelligent Delivery of Military Lessons learned. College of Information Science and Technology*, Drexel University, Philadelphia, USA.